

Cognitive Test-bed for Wireless Sensor Networks

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Abstract—Cognitive Wireless Sensor Networks are an emerging technology with a vast potential to avoid traditional wireless problems such as reliability, interferences and spectrum scarcity in Wireless Sensor Networks. Cognitive Wireless Sensor Networks test-beds are an important tool for future developments, protocol strategy testing and algorithm optimization in real scenarios. A new cognitive test-bed for Cognitive Wireless Sensor Networks is presented in this paper. This work in progress includes both the design of a cognitive simulator for networks with a high number of nodes and the implementation of a new platform with three wireless interfaces and a cognitive software for extracting real data. Finally, as a future work, a remote programmable system and the planning for the physical deployment of the nodes at the university building is presented.

Index Terms—Test-bed; Cognitive Wireless Sensor Networks; Cognitive platform; ISM bands; Simulator.

I. INTRODUCTION

Nowadays, Wireless Sensor Networks (WSNs) are subject to development and deployment constraints. One of their main problems is the increasing RF spectrum saturation at the unlicensed bands, such as the worldwide available 2.4 GHz band. Applying Cognitive Networks (CNs) to WSNs results in the new Cognitive Wireless Sensor Networks (CWSNs) paradigm, aimed at improving spectrum efficiency and wireless communications. Introducing Cognitive Radio (CR) capabilities in WSNs provides many benefits by implementing a more efficient and dynamic way to use the spectrum. However, there are also some challenges to address such as resources consumption, sensing mechanisms, energy efficiency, collaboration or decision making.

In order to enable and promote this new paradigm, an effort to develop devices and test-beds for this technology is necessary. However, despite the potential of CWSNs, due to their early research stage they are not yet deeply explored. Real or simulated scenarios scarcely exist and this contributes to the shortage of results in this area.

This paper presents a test-bed framework conceived to encourage research in CWSNs. It consists in a set of versatile and modular platforms which provides access to three different RF spectrum bands. The design, implementation and test of the platform is accomplished with promising results. The main objective of this work is to deploy a real test-bed that allows the test of different strategies, algorithms and configurations in order to advance the state of the art of CWSNs. A simulator based in Castalia, modified to allow cognitive capabilities in

TABLE I
PLATFORMS COMPARISON SUMMARY

	TmoteSky	TelosB	EyesIFX	USRP	cNGD
Controller	MSP430	MSP430	MSP430	FPGA	Microchip
WSN oriented	YES	YES	YES	NO	YES
interfaces	1	1	1	*	3
Band (MHz)	2400	2400	868	*	433 868 2400
Low power mode	YES	YES	YES	NO	YES
RAM	10 kB	10 kB	10 kB	*	64kB
Peripheral header	NO	NO	YES	NO	YES

WSN, has been developed together with the real platforms. The simulator allows the extraction of results in big network scenarios when real devices are impossible to deploy. Hardware and software models are developed and combined to create a powerful instrument useful for research in CWSNs.

II. RELATED WORK

Because of the novel stage of CWSNs there are not many specific devices or simulators to test applications, strategies and services. Besides, current implementations are very poorly featured yet, not fulfilling researchers' requirements. It is natural that most current works are based on plain WSNs or on Software Defined Radio (SDR).

On the one hand, there are many different types of devices for WSN platforms that share similar characteristics: low power, memory and processing constraints, and operation over Industrial, Scientific and Medical (ISM) bands. TmoteSky [1], TelosB [2], or EyesIFX [3] are some of the most important WSN devices. However, none of them have different Radio Interfaces (RIs) and their radio reconfiguration capabilities are very limited. On the other hand, many SDR platforms have been developed to support individual research projects, but these platforms do not respond to CWSNs requirements. The Berkeley Cognitive Radio Platform [4] (based on the BEE22), OpenAirInterface [5] (proposed by the mobile communications department at EURECOM), or the Universal Software Radio Peripheral (USRP) [6] are the most important ones.

For simulators, the main contribution is the library for cognitive simulation present in NS2/NS3 [7], one of the most common WSN simulators. However, models, parameters, and

TABLE II
TESTBED COMPARISON SUMMARY

	TWSIT	VT-CORNET	cNGD TestBed
WSN oriented	YES	NO	YES
Multiple interface platform	NO	NO	YES
interfaces	2	*	3
Wireless Programming	NO	NO	YES
Low Power	YES	NO	YES
Peripheral header	NO	NO	YES

results are still quite poor and inaccurate. Simulators based on OMNeT++ are widely used too. MiXiM [8] and Castalia [9] are WSN simulators based on OMNeT++. The SENDORA project [10] produced a high amount of papers and literature. Nevertheless, the software it developed has been sidelined by the results of other simulators.

As a complete test-bed, TKN Wireless Indoor Sensor network Test-bed (TWIST) [11], developed by the TKN at the TU Berlin, is one of the largest academic test-beds for experimenting with WSN applications at indoor deployment scenarios. It provides basic services like node configuration, network-wide programming, out-of-band extraction of debug data and gathering of application data. It also presents several novel features such as active control of the power supply of the nodes. Currently, the setup consists of 102 TmoteSky nodes operating at 2.4 GHz and 102 eyesIFX nodes at 868 MHz resulting in a fairly regular grid deployment pattern with an inter-node distance of 3 m. However, the nodes used at TWIST do not possess frequency agility beyond their single frequency band. Hence, none of them can be considered CWSN nodes. Even though the test-bed constitutes an approach, it is not a completely valid and trustworthy CWSN platform yet.

The Virginia Tech COgnitive Radio Network Test-bed (VT-CORNET) [12] is a collection of cognitive nodes deployed in a building on the Virginia Tech campus. The test-bed consists of a total of 48 static SDR nodes based on USRP210, located at the ceiling. In addition to the static nodes, low-power mobile nodes are also available in order to provide an environment that accommodates a wide variety of research topics. Nevertheless, the devices used at this test-bed are not real WSN nodes since they are based on SDR. These RIs are not suitable for WSNs because of their high power consumption. Despite their possibilities for frequency mobility, the solution implemented by this test-bed is not a real CWSN implementation.

III. APPROACH

The proposed test-bed consists of two elements. The first is the cognitive New Generation Device (cNGD), a new platform that responds to WSN criteria introducing cognitive capabilities. It has access to three different free spectrum bands, thus making it a very powerful tool for CWSN research and development.

Secondly, the deployment of networks with a high number of real devices is very difficult and expensive. This is the great

advantage of the introduction of simulators. By adding data taken from functional prototypes to the simulation process, the accuracy of simulations is improved.

Thus, the combination of both elements results in a complete and useful framework to promote CWSN research.

A. Cognitive simulator

The CWSN simulator described in this section is based on the Castalia simulator. Previous attempts to create a cognitive simulator [13] have not reached a decent level of development. This have led us to create our own cognitive simulator based on a WSN simulator. Castalia provides us with a modular and simple implementation based on OMNeT++, energy and memory monitoring and realistic physical and radio models.

Emphasizing the physical and radio layer, Castalia offers multiple characteristics such as path loss, mobility in the nodes, simple interferences, multiple modulations and sleep modes. The cognitive simulator can use all these features in order to create more realistic scenarios.

In this work the structure of Castalia has been modified in order to provide the simulator with cognitive radio support. In the new model, the nodes have multiple communication modules which can be configured with different parameters. This simulates multiple interfaces in a wireless node. The new simulator provides the developer with functions to change the default interface used to send data. The radio module of each communication module provides new API methods for changing the active channel.

Another change implemented in the simulator is the creation of Primary Users (PUs) and Secondary Users (SUs). Most cognitive applications have both roles, where PUs have preference in the use of the spectrum and SUs try to take advantage of the spectrum holes. The application layer is responsible for providing this feature.

These changes transform Castalia into a simulator capable of running CR experiments, although it still lacks any cognitive capabilities. In order to turn Castalia into a real cognitive simulator it has been equipped with a new module that includes all the cognitive features of the nodes.

The CRModule structure is shown in Figure 1. It is composed of six elements, extracted from work [14]. These modules have been adapted to the existing Castalia structure and allow the developer to simulate different scenarios. Therefore, multiple interactions between these modules exist.

The Repository stores the information captured by the nodes. Each node publishes a part of its own repository to the network, making it public through the Virtual Control Channel (VCC). The Access submodule controls which part of the repository is public and which nodes are allowed to access it. The Policy submodule is a set of weighting parameters that control the priority of the different network goals. The Optimizer is the most complex submodule of the CRModule. It processes the Repository information bearing in mind the requirements imposed by the Policy submodule. The Executor carries out the actions derived from the Optimizer decisions. Finally, the VCC is a new method for sharing cognitive

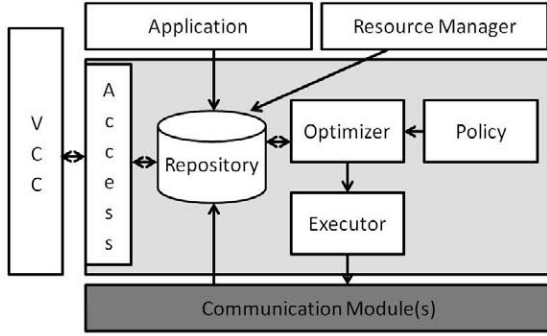


Fig. 1. Cognitive Radio Module structure

information among the CR modules. It allows CR modules to be aware of their surroundings and even of the whole network. The VCC gives the nodes a common interface to communicate among each other, ignoring the details of how the information is delivered and the precise nature and location of the communication partners.

B. Cognitive New Generation Device

Because it is a CWSN device focused on testing, its hardware should provide full capabilities. Modularity and versatility are crucial. The software architecture must provide advantages when implementing cognitive strategies in order to be a valuable tool.

The node deployed is based on a single core unit. The cNGD block diagram is shown in Figure 2.

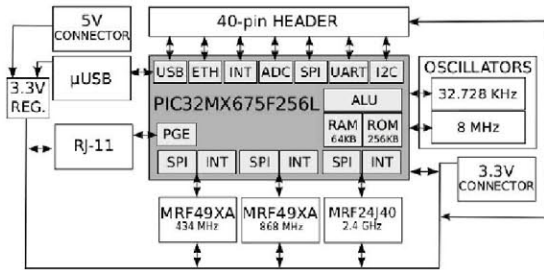


Fig. 2. cNGD block diagram

The control core is a PIC32MX675F256L, being replaceable by the larger flash memory version if needed. This microcontroller is a 32-bit core, which although may seem too high-end for CWSNs, fits the requirements for a test-bed tool. Radio interfaces are based on the MiWiTM protocol, an IEEE 802.15.4 Microchip proprietary standard for Wireless Personal Area Networks (WPAN). The cNGD contains three radio interfaces operating at three different ISM bands: 434 MHz, 868 MHz and 2.4 GHz. This feature is one of the most important of the platform and makes it the only CWSN node with access to three different spectrum bands.

The transceiver modules used for the 433 MHz and 868 MHz bands are ad hoc developments based on the MRF49XA Microchip device. They had to be developed from scratch because of the non-existence of modules operating in these

bands that fit the size requirements of our platform. The module used for the 2.4 GHz band is the MRF24J40MA from Microchip.

The device allows easy access to the peripherals through headers since it is not designed for a specific kind of application and must be useful as a development platform. This feature makes the platform attractive for researchers as it presents a huge versatility. For that purpose, the device has two 20-pin expansion headers that allow access to peripherals like ADC, I2C, SPI, Ethernet, or USB GPIOs.

The device is autonomous in terms of energy. It can be powered with 5V (from USB) or 3.3V. The device can also be powered from a pack of 3 AA Ni-Mh batteries. A picture of the final cNGD implementation can be seen in Figure 3.

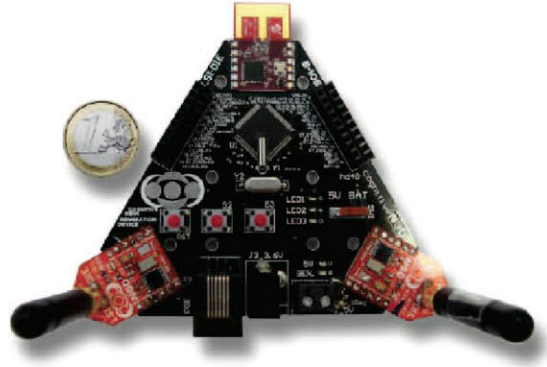


Fig. 3. cNGD platform

Regarding software, as a development platform, the software architecture must provide advantages when implementing cognitive strategies in order to be a valuable tool. Due to the fact that the microcontroller and the RF transceivers belong to the same manufacturer, their integration has been manageable, thereby reducing resources consumption and facilitating network management tasks.

The MiWiTM stack was conceived to be used with a single RF transceiver radio, so an arduous task of integration had to be performed. As a result, a firmware was obtained that combines the stacks and manages the three RF interfaces as a whole. Without this integration, the solution would be to replicate the MiWiTM stack three times, resulting in a very inefficient use of resources. With the new firmware, a memory saving of over 30% is obtained. In the process of integration, modularity and versatility of the platform has also been taken into account, making this firmware easily adjustable to different node configurations.

Along with the integrated firmware, a Hardware Abstraction Layer (HAL) has been developed with the aim of detaching researchers from the particularities of the firmware. This HAL offers a number of useful functions in CWSNs: network initialization and maintenance, power management, spectrum sensing and reconfiguration of RF interfaces.

Together with the firmware and HAL, a software unit called CRModule has been developed. This module carries out all the cognitive tasks. Just like the simulator, the cognitive architec-

TABLE III
CNGD RESULTS SUMMARY

	434 MHz RI	868 MHz RI	2.4 GHz RI
Transmission channel switch	30.45ms	30.4ms	0.151ms
Transmission power change	55.8us	55.8us	70.1us
Sleep and wake up	15.4ms	15.4ms	0.364ms
Protocol management tasks	1.3us	1.2us	1.2us
Spectrum energy scan	194.4ms	908ms	410.13ms
Effective application rate (broadcast)	28.94kbps	31.25kbps	28.8kbps
Effective application rate (unicast)	20.67kbps	24.51kbps	28.47kbps

ture implemented in the device is based on the Cognitivity Brokerage. The CRModule also uses the HAL to perform the cognitive strategies.

IV. COGNITIVE TEST-BED

Section I introduced the main goal of this project, the creation of a complete test-bed for Cognitive Wireless Sensor Networks. After the creation of the cognitive platform and the simulator, the next steps include the network-level testing, the physical deployment and the remote programming development.

The cognitive nodes have been tested in order to verify the functionality of their hardware and software. As a summary of the tests, some results are given in Table III.

New tests need to check some features such as the range of the interfaces or the stacks' scalability. Once these tests have been performed, the final deployment will be carried out. The deployment will take place at the E.T.S.I. Telecomunicación at Universidad Politécnica de Madrid. It will cover seven rooms and two floors covering more than 30 meters in each floor. The deployment will take into account the nodes' range and the power sources. The platform is autonomous in terms of battery, but some nodes will be powered from USB or the electrical grid depending on their roles.

Another important goal is the development of a remote programming system. This feature will allow any user to remotely program their cognitive strategies in all the nodes. The remote programming system includes two different parts: the wake-on radio and the wireless bootloader. Wake-on radio technology will be used in order to make all node interfaces available for the execution of the strategies. An extra-low power hardware, developed in the laboratory, will be adapted to the cNGD. When a wake-on pulse is detected, the node will change its status to bootloader mode and the user will be able to program the memory through a wireless interface. This way, the running strategies and the programming system shall not interfere with each other.

V. CONCLUSION

Cognitive Wireless Sensor Networks have emerged as a really efficient solution for multiple applications such as security control, hostile transmission environments, spectrum

optimization and energy saving. In order to encourage the development of these cognitive techniques, real test-beds are crucial.

In this work we have presented a new cognitive test-bed for Wireless Sensor Networks constituted by a new platform with three different interfaces in ISM bands. Moreover, these nodes run an optimized software that controls the three communication stacks. The platform and the complete test-bed are enriched by a cognitive simulator. Multiple scenarios and approaches have been previously tested in this simulator in order to check the viability of the solution.

The advantages of this solution over previous test-beds are the possibility to have three different interfaces in three ISM bands, an optimized and integrated software that abstracts the developers from the hardware and a wireless programming system. It allows the test-bed to be completely wireless and not interfered by physical wires.

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